NASA Technical Memorandum 87583

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(NASA-TM-87583) THERMAL FATIGUE TESTS OF A RADIATIVE HEAT SHIELD PANEL FOR A HYPERSONIC TRANSPORT (NASA) 31 p Avail: NTIS HC A03/MF A01 CSCL 11F

N87-28643

Unclas
G3/26 0097834

GRANVILLE L. WEBB, RONALD K. CLARK, AND
ELLSWORTH L. SHARPE

SEPTEMBER 1985

Date for general release September 30, 1987

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

THERMAL FATIGUE TESTS OF A RADIATIVE HEAT SHIELD PANEL FOR A HYPERSONIC TRANSPORT

Granville L. Webb

Ronald K. Clark

Ellsworth L. Sharpe

ABSTRACT

A pair of corrugation stiffened, beaded skin René 41 heat shield panels were exposed to 20,000 thermal cycles between room temperature and 1450°F to evaluate the thermal fatigue response of René 41 metallic heat shields for hypersonic cruise aircraft applications. At the conclusion of the tests, the panels retained substantial structural integrity; however, there were cracks and excessive wear in the vicinity of fastener holes and there was an 80-percent loss in ductility of the skin. Shrinkage of the panel which caused the cracks and wear must be considered in design of panels for TPS applications.

INTRODUCTION

Design of structures to operate efficiently for long periods in the severe thermal environment encountered by hypersonic cruise aircraft requires careful selection of materials and structural concepts. Among the concepts that have undergone evaluation at Langley Research Center are actively cooled panels which utilizes hydrogen fuel as the heat sink to cool the metal structures (ref. 1). Actively cooled panels may be bare panels that rely totally on active cooling (ref. 1) or may use passive overcoats (ref. 2), or radiative heat shields (refs. 3, 4) to reject some of the heat. Each of these forms of actively cooled panels has a region of heat flux where it represents the optimum concept structural/thermal management (ref. 2).

Studies of the significance of heat sink matching and the mass penalties associated with high-level cooling (refs. 5-7) point to the advantage of utilizing passive thermal protection systems and actively cooled panels for hypersonic aircraft. Reference 3 summarizes results from design and fabrication of a lightweight René 41 radiative and actively cooled panel which consists of corrugation-stiffened, beaded-skin René 41 heat shields backed by a thin layer of high-temperature insulation contained within stainless steel foil packages to seal against water ingress, and by an adhesively bonded aluminum-honeycomb-sandwich structural panel with coolant tubes next to the outer skin. The panel successfully completed thermal/structural tests to verify its performance (refs. 8-9). While the thermal/structural performance of the René 41 heat shield has been verified, the response to thermal fatigue has not been defined. The present paper presents results from thermal fatigue tests of the corrugation-stiffened beaded-skin, René 41 heat shield. The heat shield was exposed to 20,000 thermal cycles in a fixture with quartz lamps. The purpose of the thermal fatigue tests was to study the spot welds of the beaded skin to the corrugation and the cutouts in the beaded skins and corrugation at the lap splice joint.

Certain commercial materials are identified in this paper to specify adequately which materials were investigated in the research effort. In no case does such identification imply recommendation or endorsement of the product by the NASA, nor does it imply that the materials are necessarily the only ones or the best ones available for the purpose. In many cases equivalent materials are available and would probably produce equivalent results.

THE THERMAL FATIGUE MODEL

The thermal fatigue model shown in figure 1 was a 10.8 inch wide by 29.9 inch long panel consisting of two corrugation-stiffened beaded-skin René 41 heat shields structurally supported by a half-inch thick aluminum plate (ref. 3). Between the René 41 heat shield and the aluminum plate was an 0.125-inch thick layer of flexible Min-k, Type HTS, stitched in an Astro-quartz cloth container. The two heat-shield panels, jointed at the center with a slip joint, were rigidly attached to the structural plate at the opposite ends. The edges of the heat shields were attached to the structural plate by bolts through slotted holes which permitted longitudinal movement of the panel. The heat shields are held at a predetermined distance above these structural plates by rigidized insulation (Mairmet 45) spacers and bolts, thus maintaining the required volume for the insulation blanket.

The size (0.090 in.) and spacing (1.0 centers, 2 rows, 0.41 apart) of the spot welds are identical to those that would be used in a full scale panel and other geometrical details including details of the lap splice joint simulate the full scale design. However, the René 41 skin thickness was 0.010 in. instead of 0.008 as would be used in the full scale design.

Figure 2 shows the partially assembled thermal fatigue model with the cutouts in the beaded skin of one heat shield panel. The cutouts of neighboring panels mate to form the lap splice joint. The cutouts along the edges of the insulation allow the spacers to rest on the aluminum structural support. Stainless steel shoulder bolts and bushings (fig. 1) were used to assemble the panel so that it is not constrained as it undergoes thermal expansion.

The heat shield panels and the aluminum plate were instrumented with cromel-alumel thermocouples to monitor and control temperatures during testing.

LABORATORY APPARATUS

Thermal fatigue tests of the model were conducted in an enclosure with remote controls provided for all the test apparatus. The apparatus was electrically isolated from the enclosure because of the high voltage supplied to the heaters. Six banks of air cooled radiant heaters were used to heat the model. Each bank contained eight quartz lamps mounted on a gold plated reflector. The quartz lamps, 0.375 in. in diameter and 25 in. long (active length), were spaced 0.5 in. apart and were rated at 2500 watts and 480 volts. A water cooled 700 amp silicon controlled reactifier (SCR) supplied power to the heater. A temperature controller and an electronic variable temperature/ time proportional programmer were used to control the heater through the desired heating cycle. Two 12 point temperature records and a digital temperature readout were used to record and monitor the temperature of the todel and the heater fixture.

Figure 3 shows the model placed on a support stand and surrounded by glass-rock rigid insulation bricks which prevented the support stand from overheating. Three cromel-alumel thermocouples, which had leads covered with high temperature insulation, were welded to the surface of the heat shields. These thermocouples were wired in parallel, connected to the temperature controller and served as the temperature control thermocouples. They were wired in parallel to create a redundant situation in case one thermocouple became open or detached from the model. Redundancy was necessary because the test was set up to run continuously until manually stopped.

TEST PROCEDURES

The heating rate (T_1) shown in figure 4 approximated the heating rate experienced during a hypersonic flight (ref. 3). Simulating the flight cooldown rates (T_1 in fig. 4) would have greatly increased the thermal cycle time. Since natural convection cooldown would not jeopardize the structural integrity of the model, it was used to limit the cycle time to 12.5 minutes as shown in figure 4. The sawtooth plot was the curve used on the proportional programer and the dashed curve (T_2) is the actual temperature on the backside corrugation. With the time/temperature proportional programmer, it was possible to run the cycles automatically once the system was checked-out. After 5000 cycles the model was removed from the test set-up, disassembled, and examined. The model was then reassembled, returned to the test stand, and the thermal cycles continued until a total of 20,040 simulated flights were achieved.

RESULTS AND DISCUSSION

The thermal fatigue model was removed from the test stand after 5000 thermal cycles for an interim disassembly and inspection. It was then returned to the test stand and the balance of the exposure program was completed, reaching a total of 20,040 thermal exposure cycles.

After 5000 Thermal Cycles

Initial examination of the model indicated that no apparent damage had occurred during the first 5000 thermal cycles which was the design life of the target hypersonic aircraft. However, while the model was being dismantled, one of the heat shields was damaged at the edge bolt holes. An examination of the damage indicated that the problem may have been avoided if more care had been exercised in disassembling the model. The bolts along the edge of the "stand-off" configuration (fig. 2) had apparently seized during thermal exposure and in loosening them, the edge of the heat shield was damaged. Figures 5 and 6 show the broken corner on the lower right of the left heat shield. These photographs also show cracked metal between the bolt holes and the lower edge on two other places on the left heat shield. Figures 7 and 8 show close-up views of the broken corner and the crack in one of the slotted holes on the side of the panel, respectively.

Excluding the region of the panel damaged during disassembly, the heat shields successfully completed the initial 5000 thermal cycles with no physical or structural damage. Figures 5, 6, and 9 show details of both sides of the heat shields which indicate that the elongated fastener holes, the cutouts at the slip joint, and the spot welds between the corrugation and dimpled sheets are intact.

After 20,040 Thermal Cycles

At the conclusion of 20,040 thermal cycles, the thermal fatigue panel was removed from the test stand and disassembled for evaluation. Examination of the heat shields disclosed a number of cracks in the elongated fastener holes. There was also some additional wear consisting of enlarged holes and worn bolts at the elongated holes.

The fasteners holding the René 41 heat shield to the aluminum plate were difficult to remove and had to be forced out to separate the heat shield from the aluminum support plate. Superficial examination of the René 41 heat shield indicated that the heat shield hole pattern was smaller than the hole pattern in the aluminum plate. Additional evidence of the mismatch of the holes can be seen in figure 10. Fastener number 3 appears almost centered in the slot of the René 41 while fasteners 1 and 6 are obviously not centered in their slots. The dimensions of both heat shield panels were checked and found to have decreased in width by about 0.10 inch. In fact, because of that shrinkage, the width of the hole pattern in the heat shields at the conclusion of the thermal fatigue test was less than for the aluminum structural plate.

Examination of the slotted holes after the panels were disassembled revealed additional information. Figures 11 and 12 show a comparison of elongated holes in the panel. The ends of the slot in figure 11 appear to be a uniform radius while the ends of the slot shown in figure 12 are flattened.

Figure 12 shows a "non-design joint" slotted hole along the side of the panel. This hole had a bushing that was free to roll as the panel expanded and contracted, so the wear appears to be uniform along the length of the slot. In contrast, figure 13 shows the slotted hole from a corner (number 6 on figure 10) of the heat shield panel. This hole contained one of the design joint's shoulder bolts. The "egging" out occurred at the cold end of the slot where the fastener is located when the thermal expansion of the panel is zero. Figures 14 and 15 show two of the six shoulder bolts used in the "design-joint." The location of the bolts was not recorded as the disassembly took place. The shoulder in figure 14 shows some damage from where the René 41 panel rubbed it during thermal expansion, but the shoulder in figure 15 is almost non existent. This suggests that the René 41 was bearing heavily on the shoulder during the thermal cycle.

Properties

Subsize tensile specimens were machined from the corrugated skins of the heat shield panels conforming to the recommended practice of ASTM E-8 (ref. 10) and tensile tests were conducted to determine the residual room temperature tensile strength and elongation of the René 41. Specimens were also machined from as-received René 41 for comparison. Figure 16 shows a comparison of tensile strength and elongation for the as-received René 41 material and for specimens machined from the thermal fatigue model. The most significant result presented here is the reduction in tensile elongation of the specimens from the exposed panel compared to that from the as-received material. Specimens from the thermal fatigue panel failed at six percent strain while the as-received material specimens failed at approximately 22.5 percent strain. The yield strength of the thermal fatigue specimen was 25 percent greater than for the as-received material.

Figure 17 shows light photomicrographs of mounted and polished samples of René 41 in the as-received condition and after thermal fatigue testing. The photomicrographs show an abundance of grain boundary precipitates in the thermal fatigue specimens compared to the specimen in the as-received condition which has clean boundaries. Based on a review of the literature for René 41, these precipitates are blocky carbides and the ψ' phase [Ni_3 (Al, Ti)] (ref. 11). The presence of ψ' within the matrix is indicated by the darkened regions of the matrix bordering the grain boundaries (ref. 12). Long time exposure to temperatures in the region from 1400°F to 2100°F may result in forming continuous grain-boundary films around the grains which produce a brittle grain-boundary network. Grain boundary precipitation to the degree shown here has a direct effect on the mechanical properties of René 41.

The damage in the corrugated skins of the heat shield in the vicinity of the elongated fastener holes was caused by the bearing loads resulting from shrinkage of the panel width. Two possible causes of the shrinkage in widths of the panels are thermal creep of the panels due to stress at temperature and microstructural precipitation of the alloy. Results from a cursory stress analysis of the corrugated skins of the heat shields indicated that stress levels as high as 45 ksi could exist in the beaded skin at the temperatures encountered during the thermal cycles, which is sufficient to produce some creep (ref. 12). The severe grain boundary precipitation noted in discussion of figure 18 has also been associated with dimensional changes in René 41 (ref. 12). It is not possible to state conclusively the extent to which these two mechanisms contributed to the shrinkage of the panels. The significant point is that René 41 is subject to creep under certain conditions and it undergoes metallurgical changes that may alter panel dimensions. Those facts must be utilized in design of the panel to preclude interference between the panel and fasteners.

CONCLUDING REMARKS

After 20,040 thermal cycles the thermal fatigue panel was found to be intact. While it had some damage, it retainted its structural and mechanical integrity to a large extent. During the thermal fatigue tests, the panel width decreased by about 1.0 percent which caused cracks and excessive wear in the area of elongated fastener holes. Shrinkage of the heat shield panels, which resulted from thermal creep and/or metallurgical changes in the alloy must be considered in design of TPS panels.

Tensile tests of specimens machined from the corrugated skins of the heat shield showed an 80-percent loss in elongation and a 20-percent increase in yield strength compared to René 41 in the aged condition. Microstructural examination of specimens from the heat shield showed severe carbide precipitation on the grain boundaries which caused the loss of ductility.

REFERENCES

1. Koch, L. C.; and Pagel. L. L.: High Heat Flux Actively Cooled Honeycomb Sandwich Structural Panel for a Hypersonic Aircraft, NASA CR-2959, 1978.

2. Kelly, H. N.; Wieting, A. R.; Shore, C. P.; and Novak, R. J.: Recent Advances in Convectively Cooled Engine and Air frame Structures for hypersonic Flight. Presented at the 11th Congress of the International Council of the Aeronautical Sciences (ICAS), Lisbon, Portugal, Sept. 10-16, 1978.

3. Ellis, D. A.; Pagel, L. L.; and Schaeffer, D. M.: Design and Fabrication of a Radiative Actively Cooled Honeycomb Sandwich Structural Panel for a Hypersonic Aircraft, NASA CR-2957, Mar. 1978.

4. Bohon, Herman L.; Shideler, John L.; and Rummler, Donald R.: Radiative Metallic Thermal Protection Systems - A Status Report. Presented at the ASME/AIAA/SAE 18th Structures, Structural Dynamics, and Materials Conference, San Diego, CA, March 21-23, 1977.

5. Pirrello, C. J.; and Herring R. L.: Study of a Fail-Safe Abort System for an Actively Cooled Hypersonic Aircraft--Volume I, Technical Summary, NASACR-2652, Jan. 1976.

6. Pirrello, C. J.; Baker, A. H.; and Stone, J. E.: A Fuselage/Tank Structure Study for Actively Cooled Hypersonic Cruise Vehicles-Summary, NASA CR-2651, 1976.

7. Herring, R. L.; and Stone, J. E.: Thermal Design for Areas of Interference Heating on Actively Cooled Hypersonic Aircraft, NASA CR-2828, Dec. 1976.

8. Shore, C. P.; and Weinstein, I.: Aerothermal Performance of a Radiatively and Actively Cooled Panel at Mach 6.6. NASA TP 1595, December 1979.

9. Shore, C. P.; Kowak, R. J.; and Kelly, H. N.: Flightweight Radiatively and Actively Cooled Panel - Thermal and Structural Performance. NASA TP 2074, October 1982.

10. E8-81 "Standard Methods of Tension Testing of Metallic Materials, 1982 Annual Book of ASTM Standards, Part 10.

11. Metals Handbook, 9th Edition, Vol. 4, Heat Treating. American Society for Metals, 1981.

12. Aerospace Structural Metals Handbook, Vol. 5, 1983 Edition.

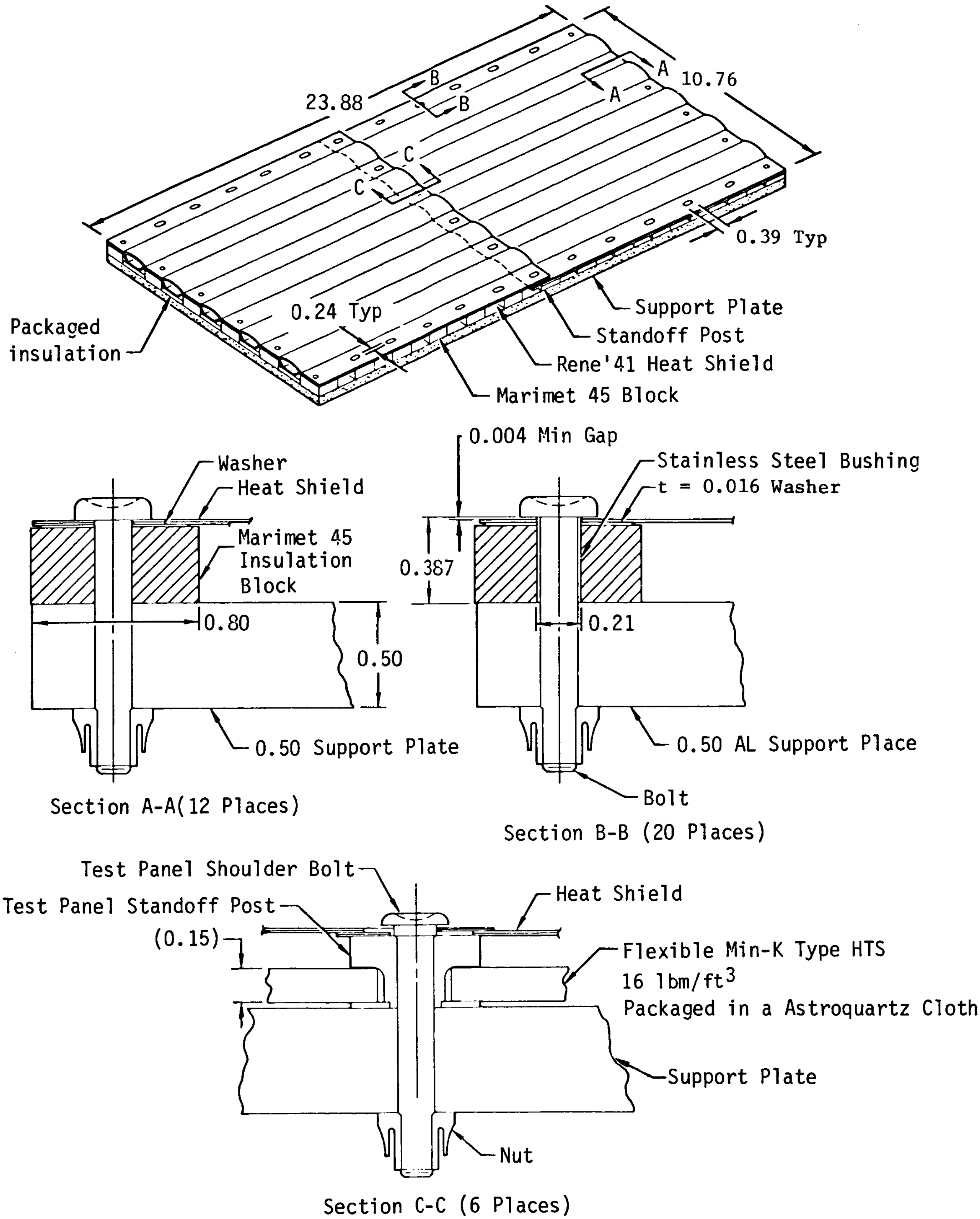


Figure 1 Thermal fatigue model

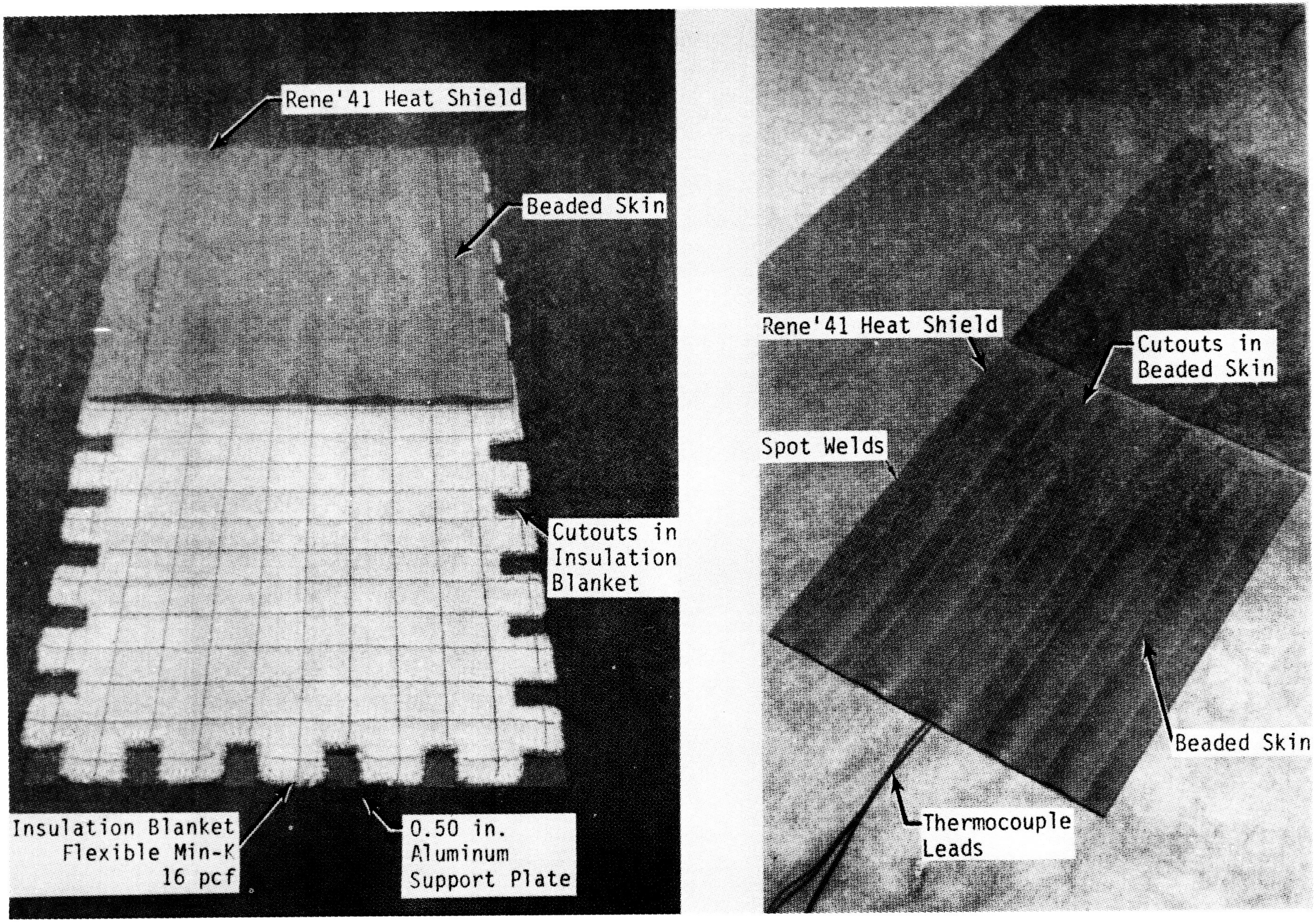


Figure 2   Partially assembled test specimen

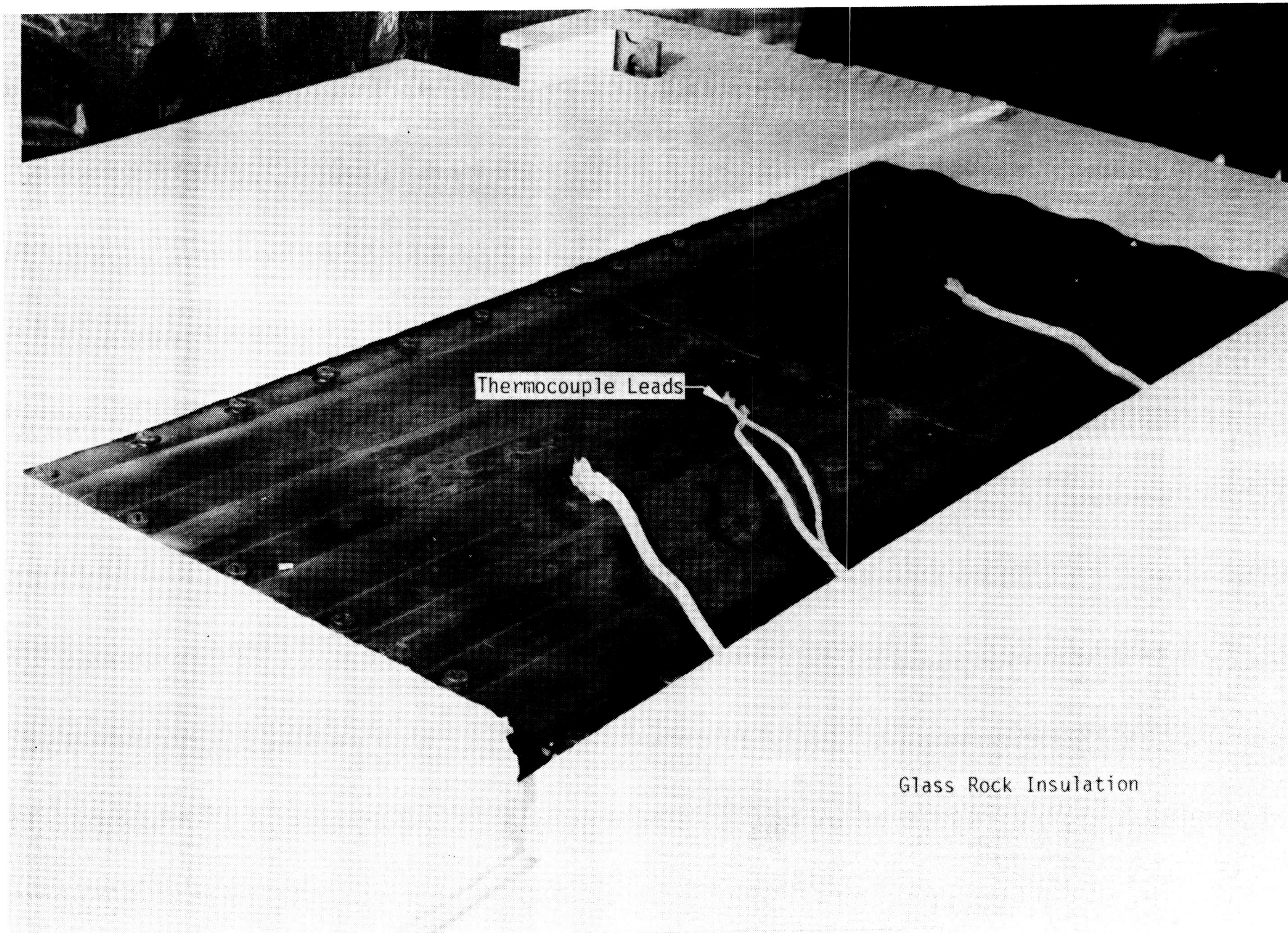


Figure 3 Model installed in apparatus

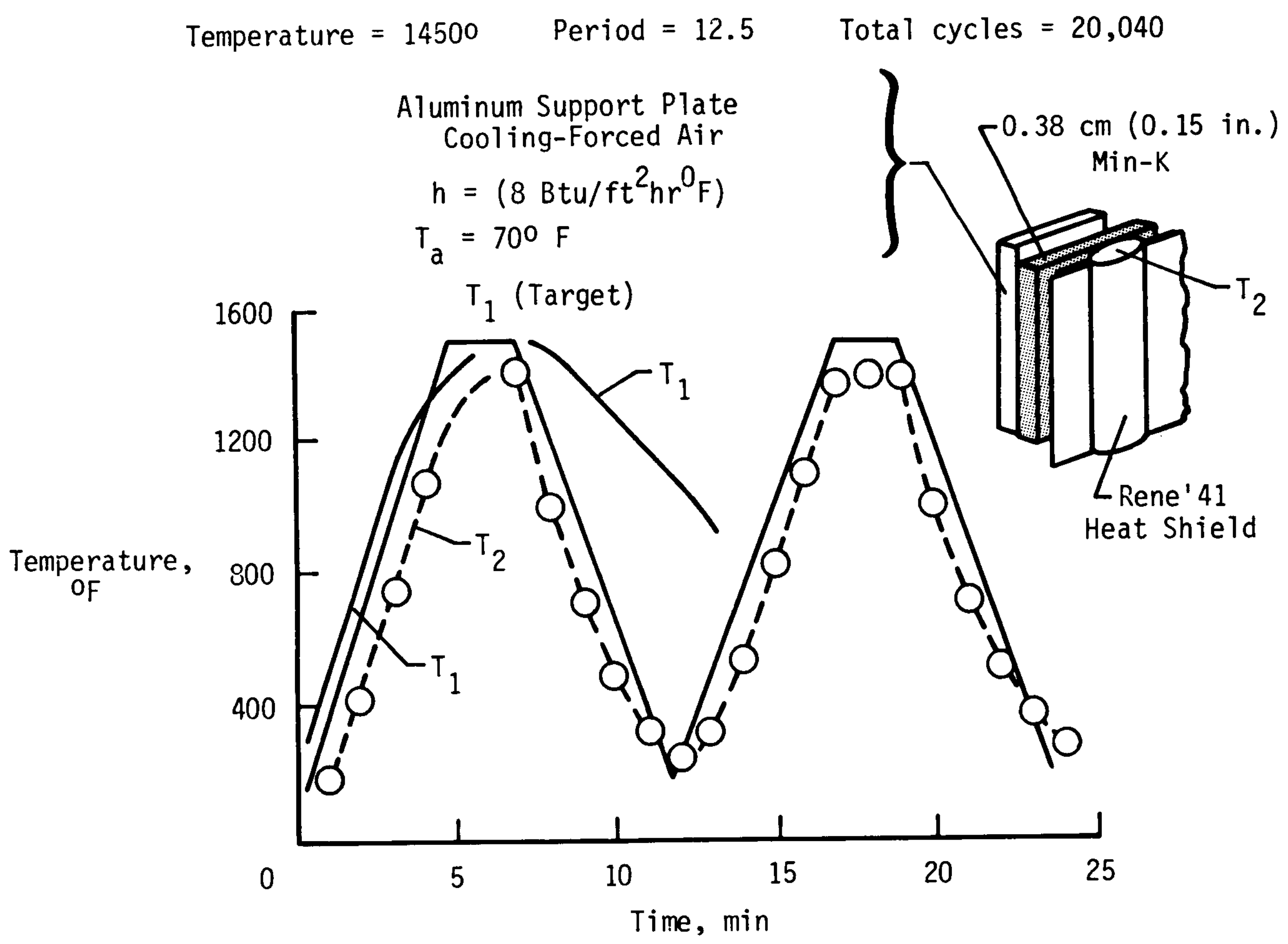


Figure 4 Test cycle for thermal fatigue model

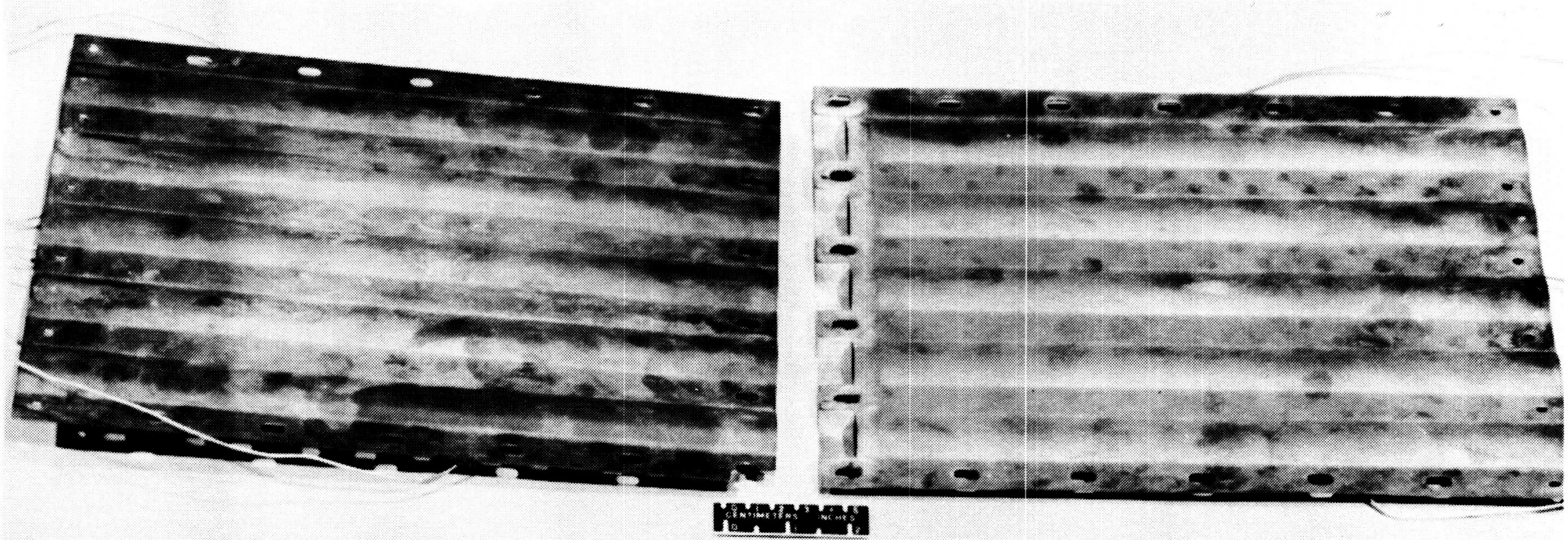


Figure 5 Heat shield after 5000 cycles

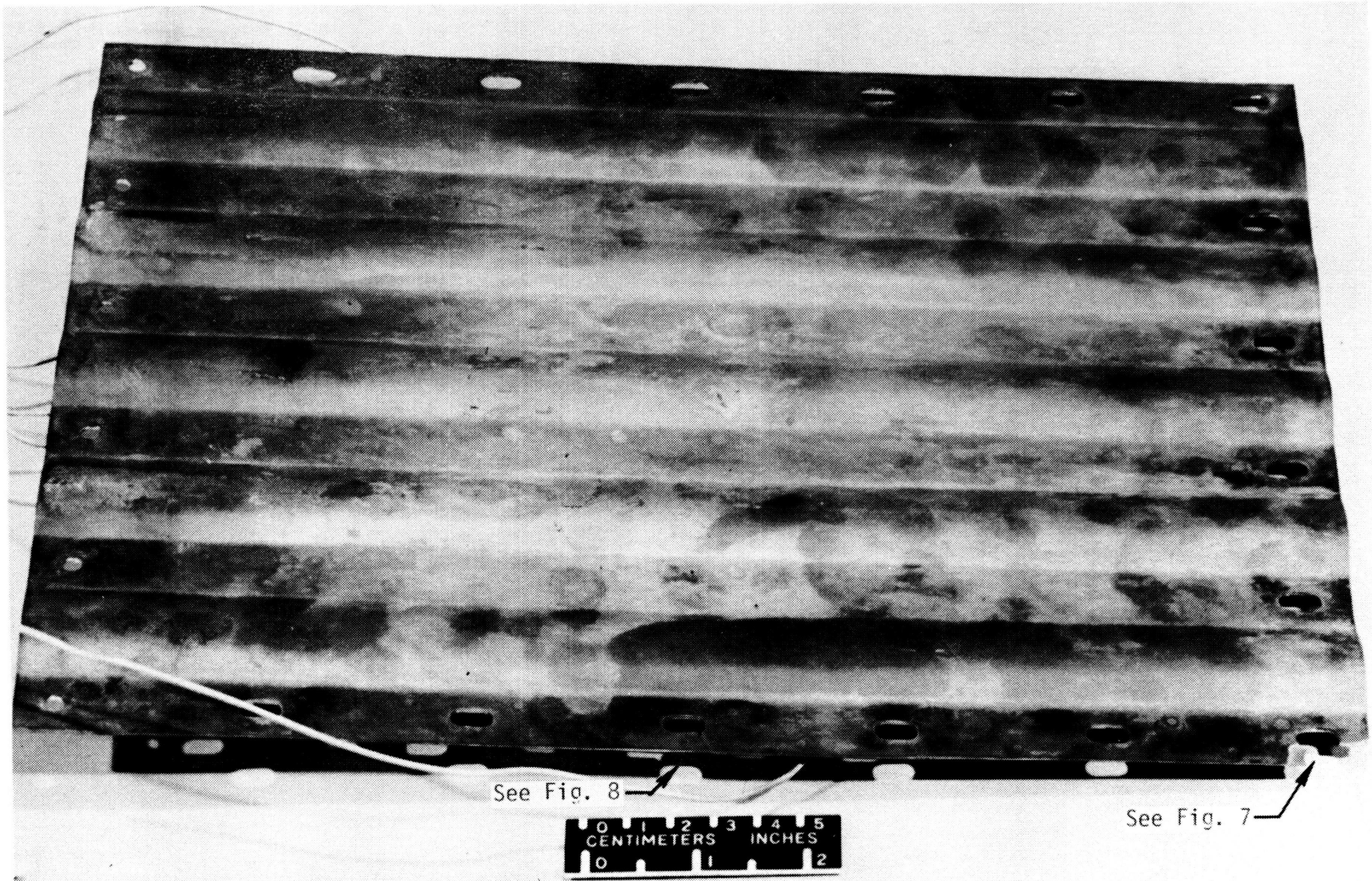


Figure 6 Overlapping panel after 5000 cycles

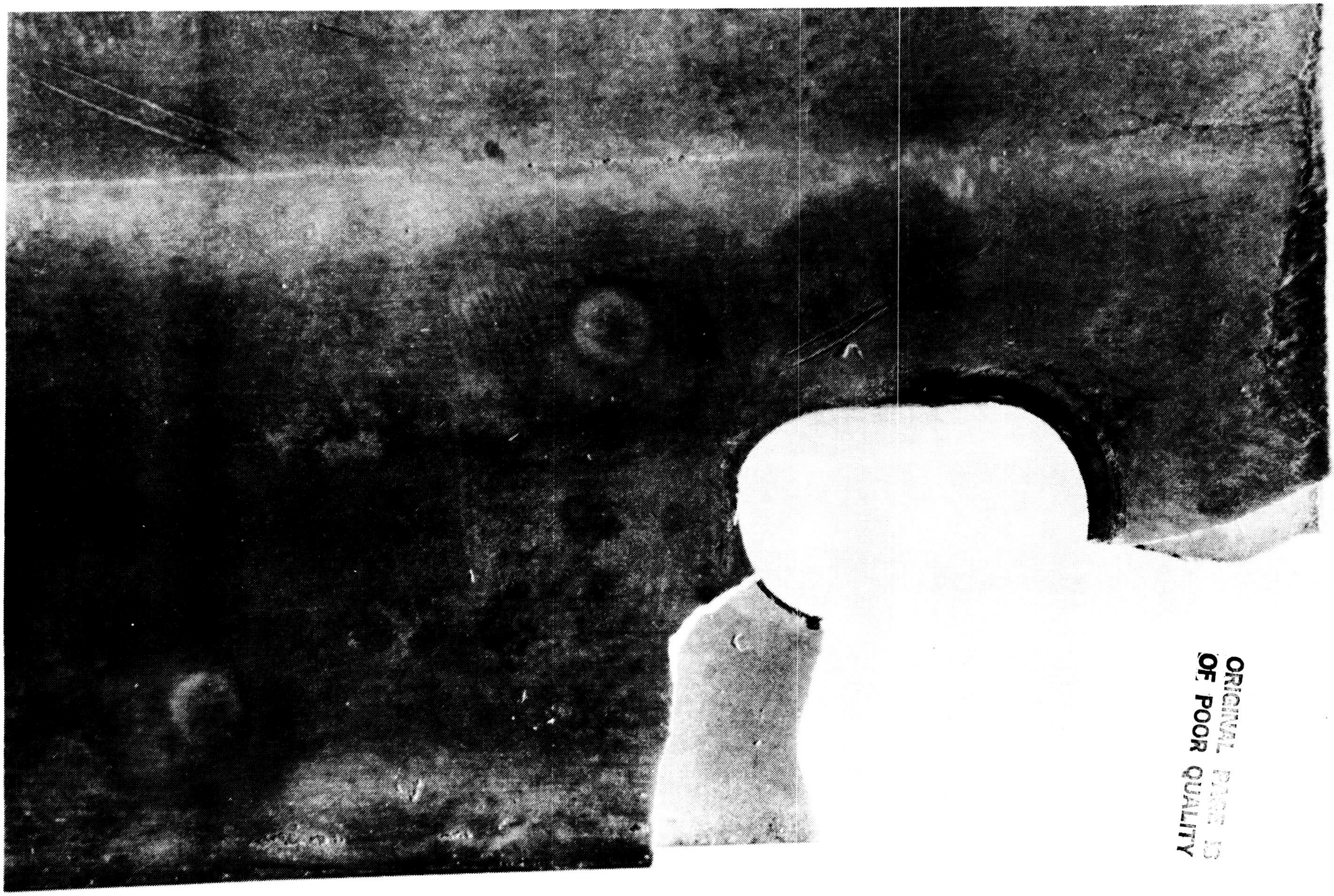


Figure 7 Broken corner

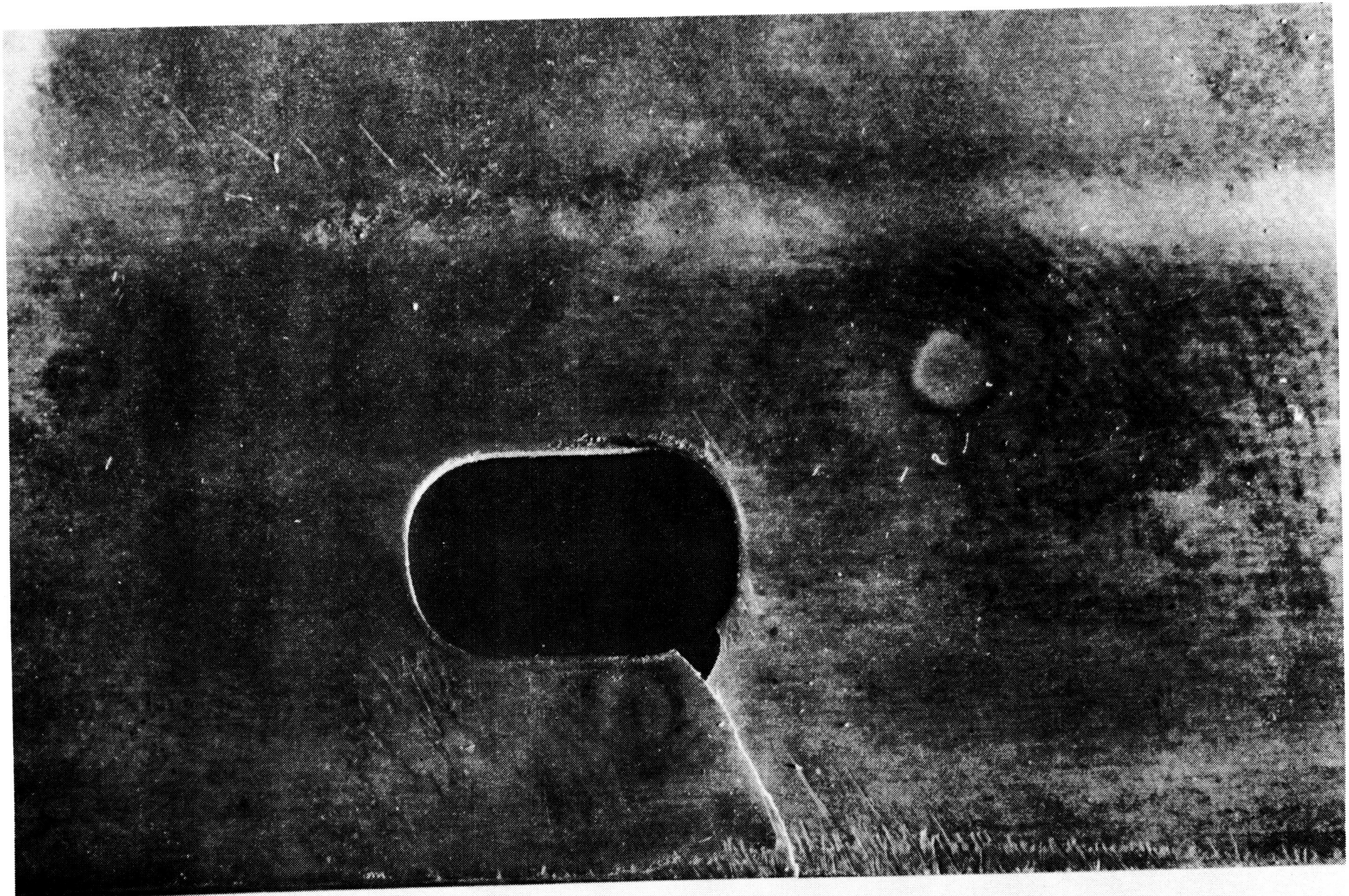


Figure 8 Damages to slotted hole on side of heat shield

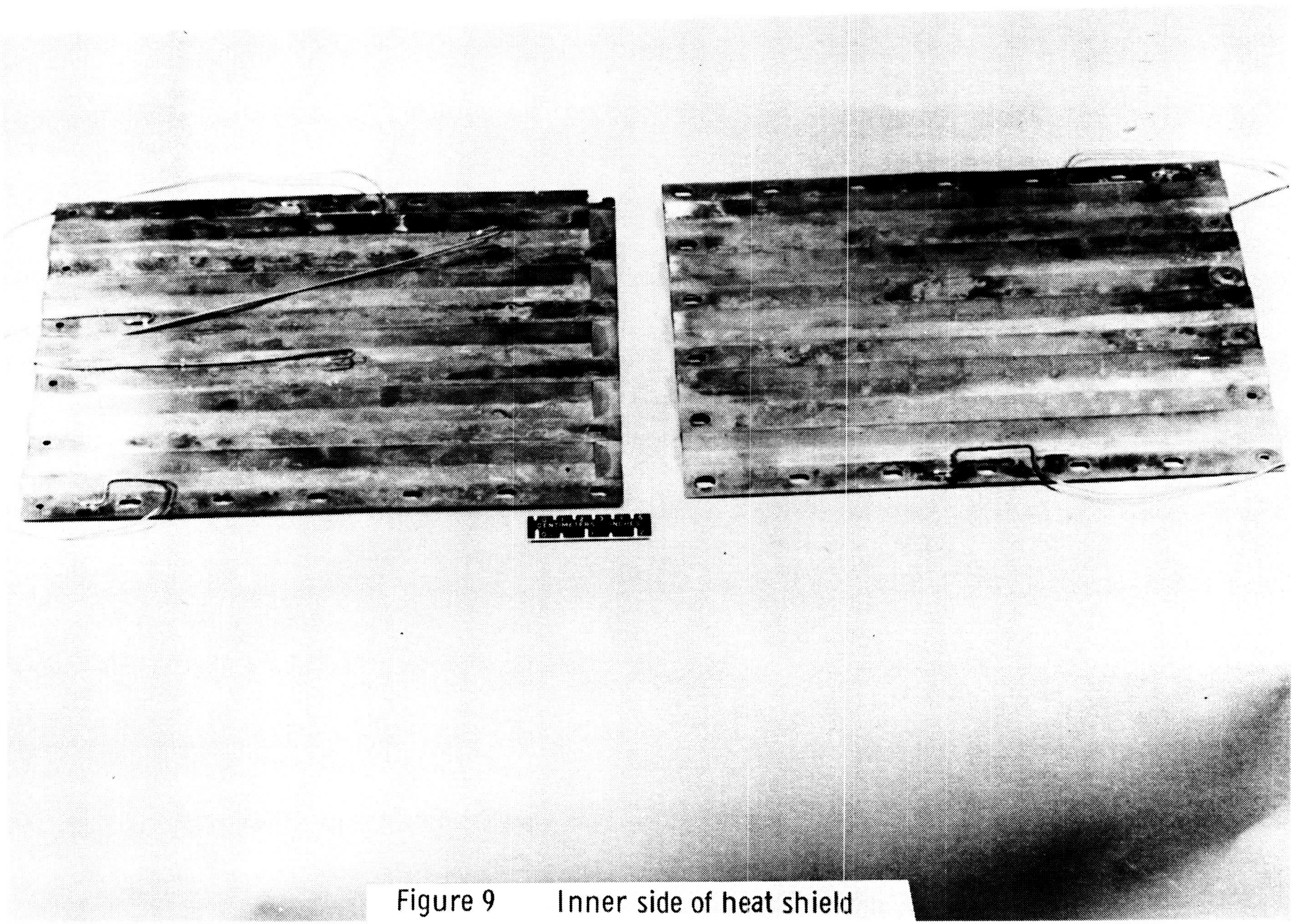


Figure 9 Inner side of heat shield

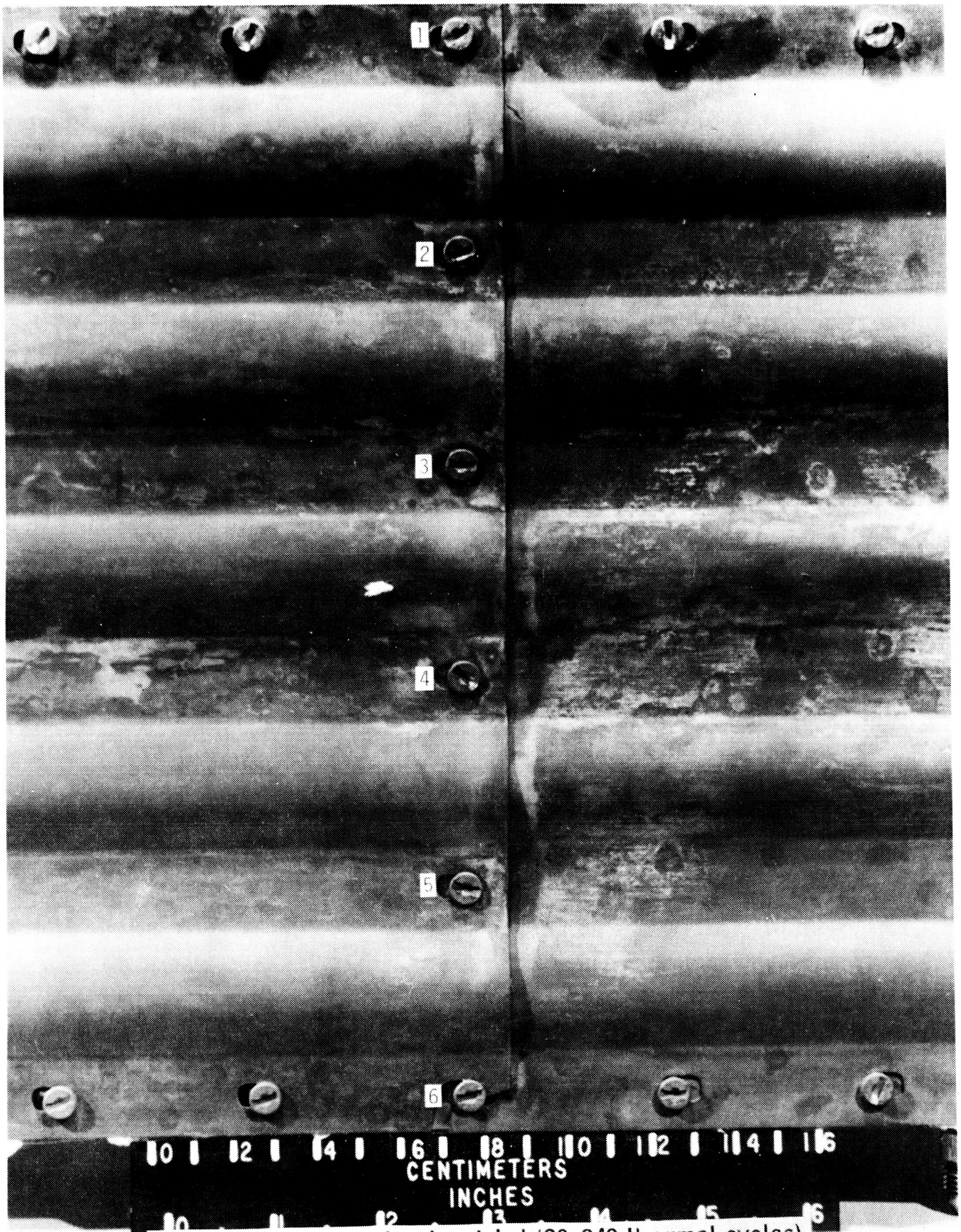
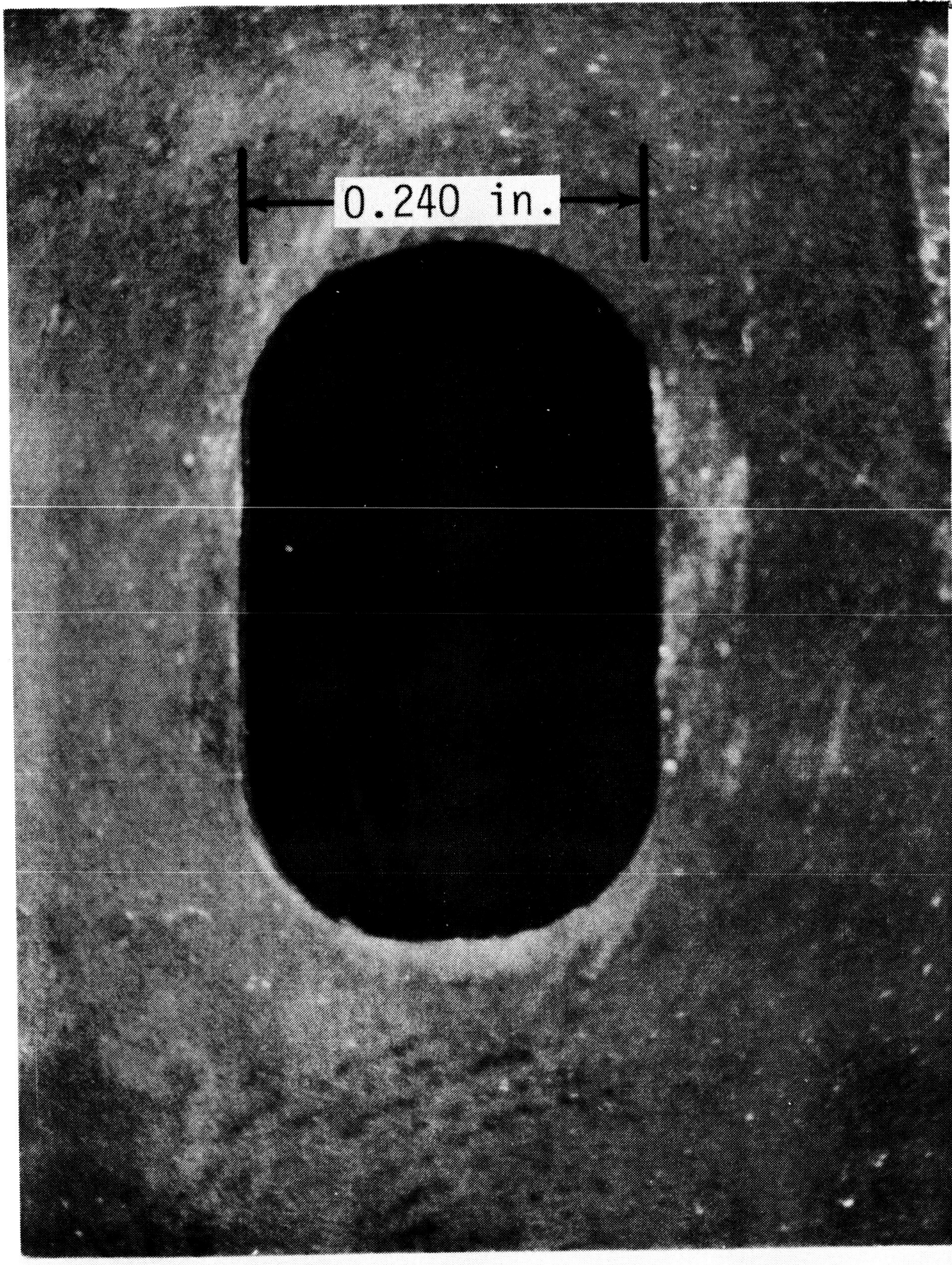
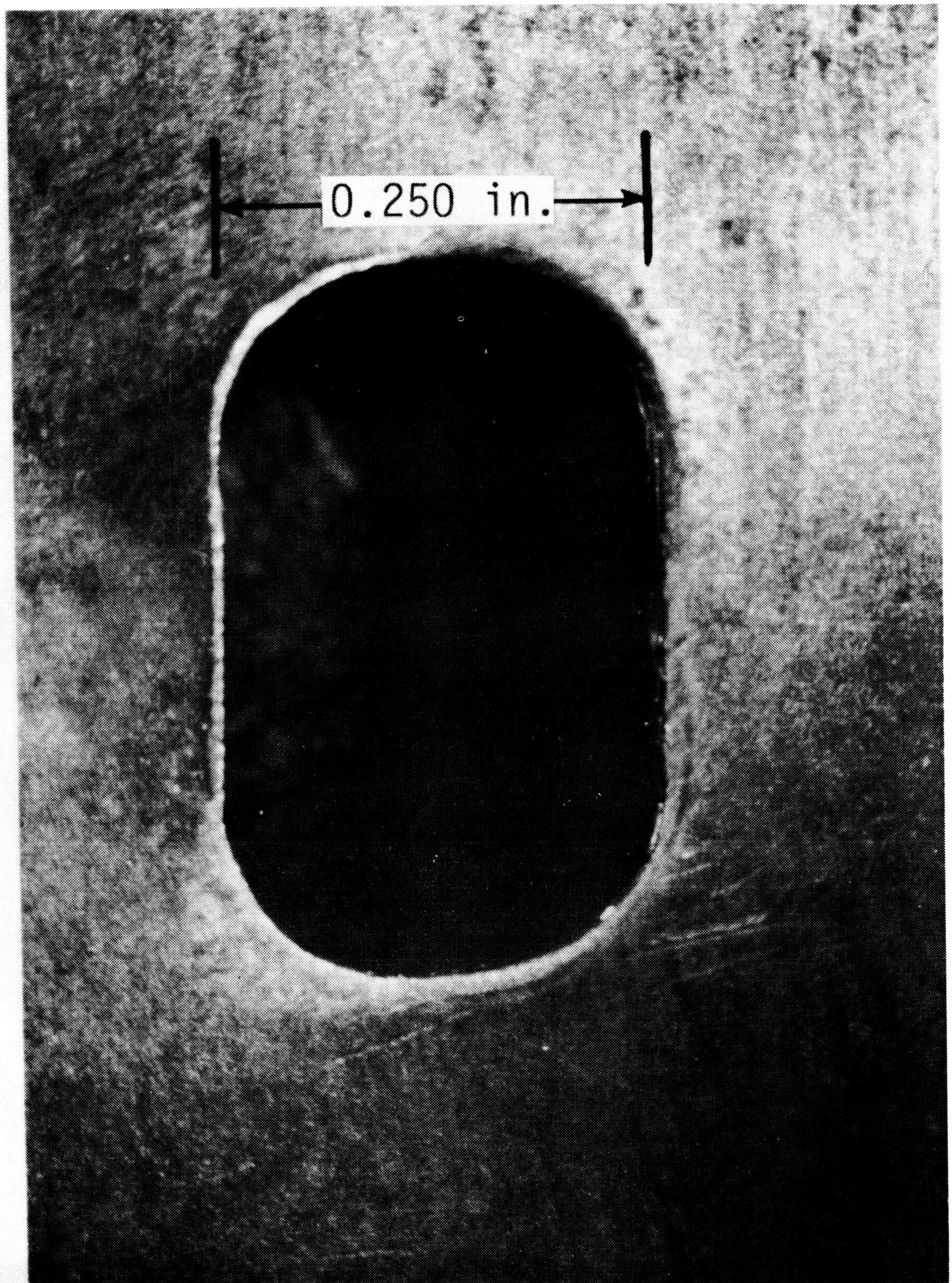


Figure 10 Overlapping joint (20, 040 thermal cycles)



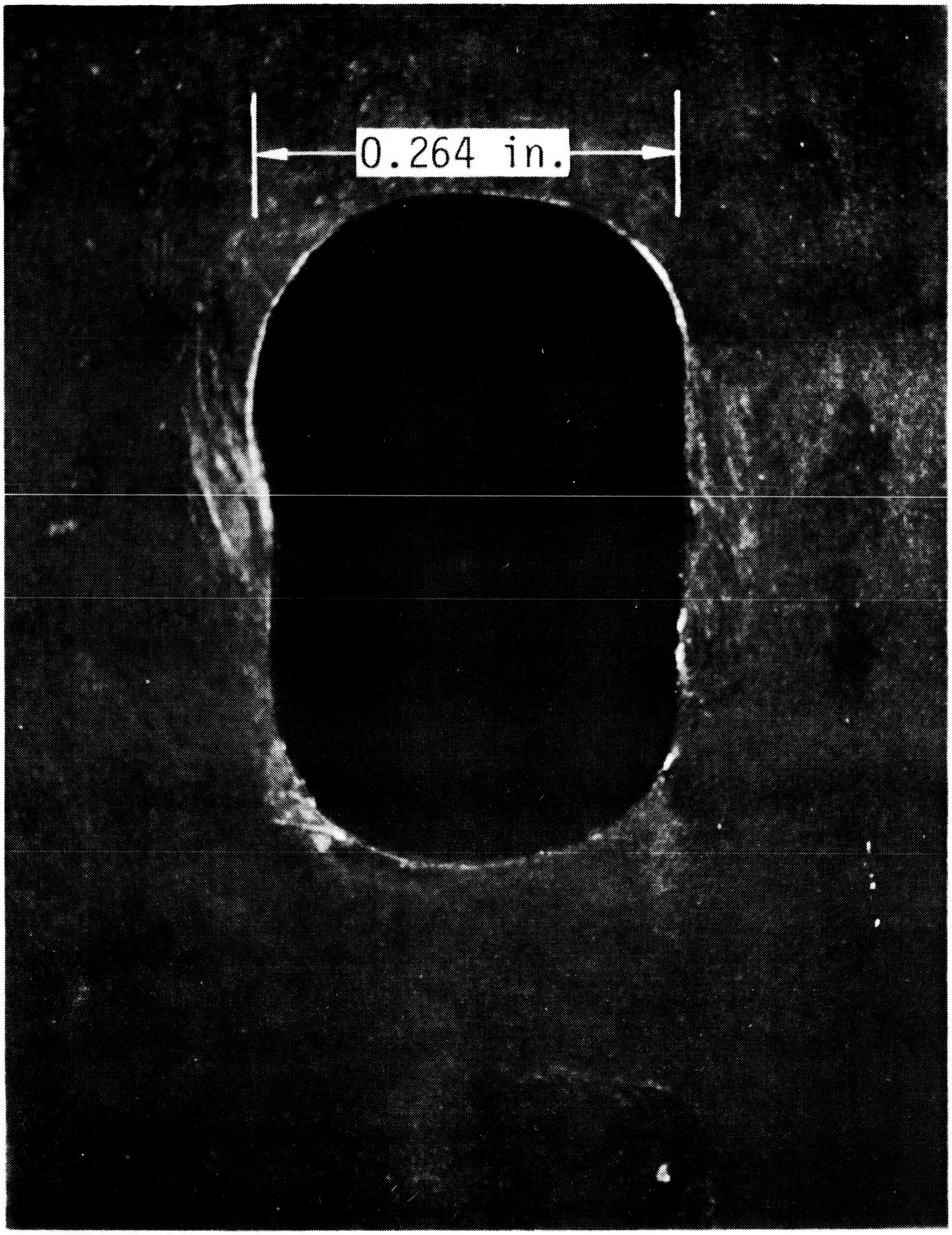
Center hole

Figure 11 Slotted hole - minimum wear (20,040 thermal cycles)



Side hole

Figure 12 Slotted hole - uniform wear (20,040 thermal cycles)



Corner Hole

Figure 13 Slotted hole - max non-uniform wear (20,040 thermal cycles)

Figure 14 Shoulder bolt - minimum wear (20, 040 thermal cycles)

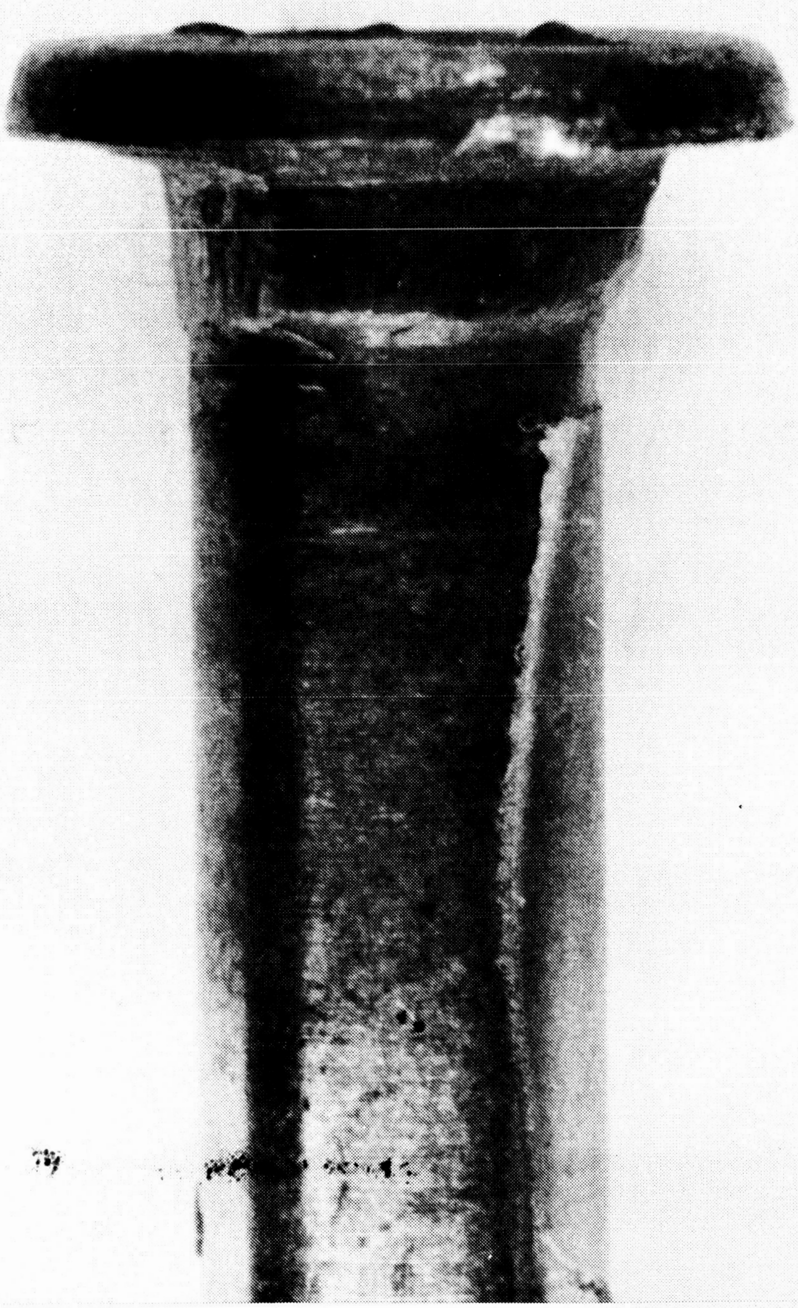


Figure 15 Shoulder bolt - maximum wear (20,040 thermal cycles)

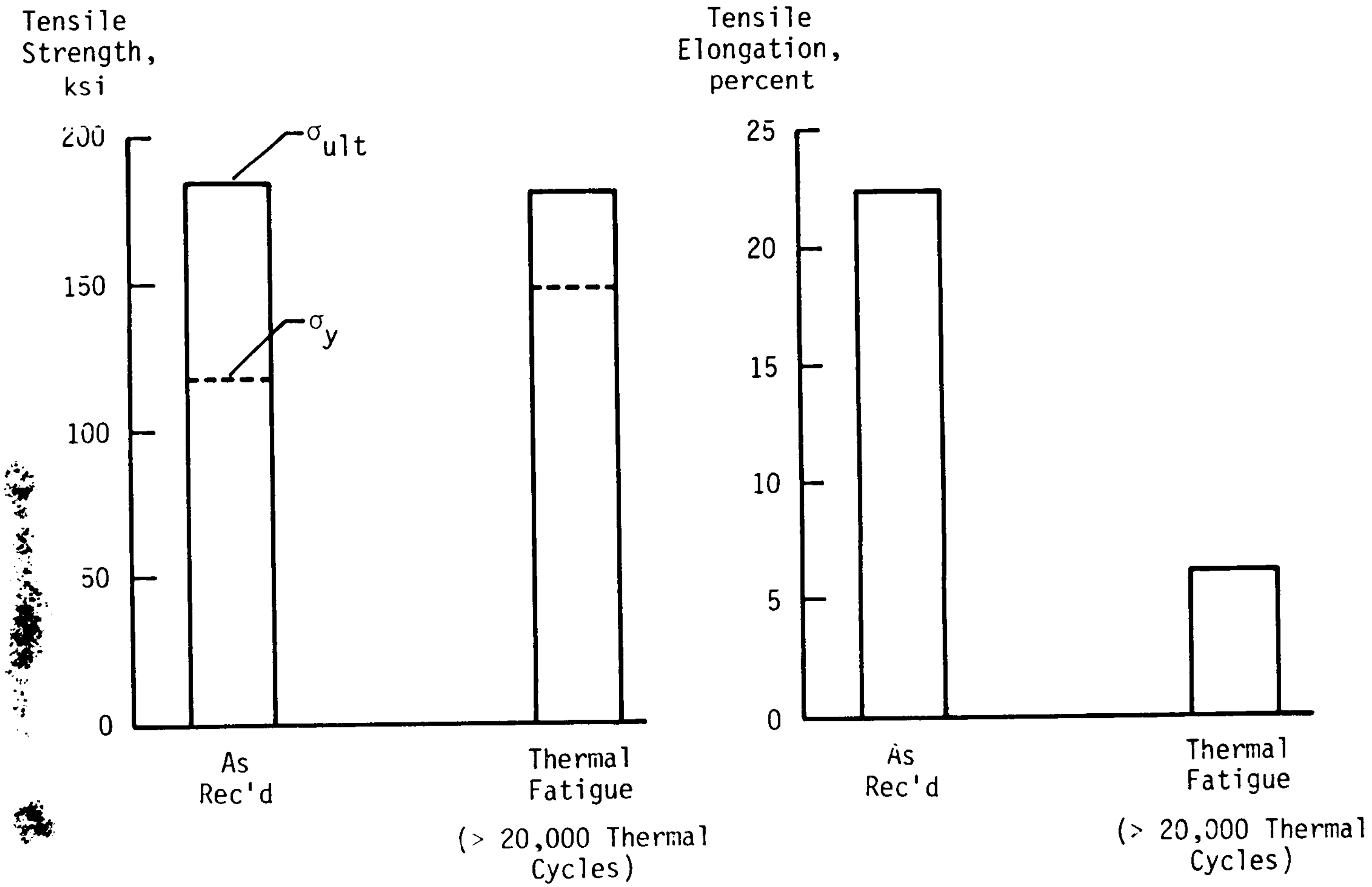
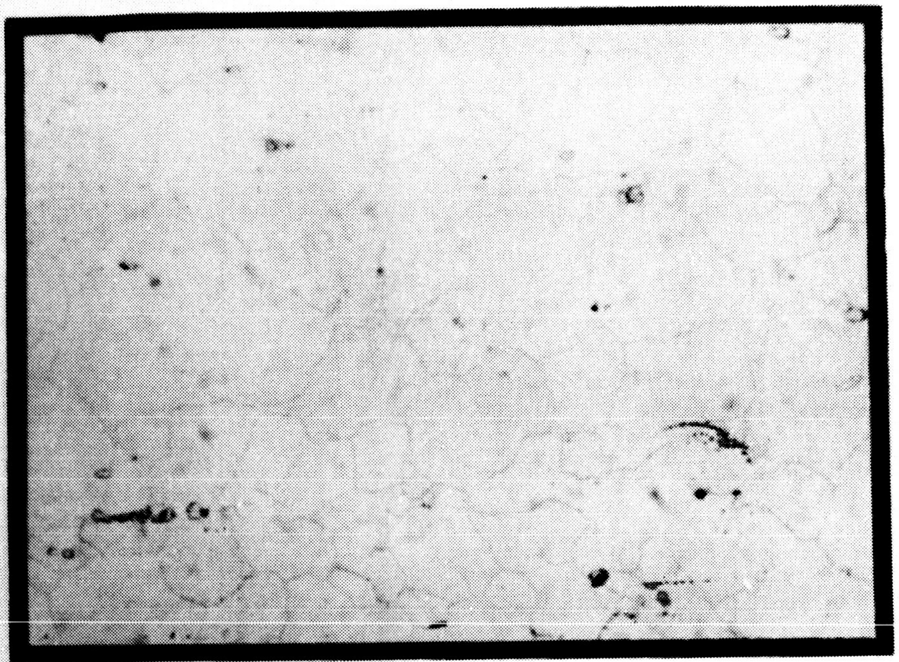


Figure 16 Mechanical Properties of Rene' 41



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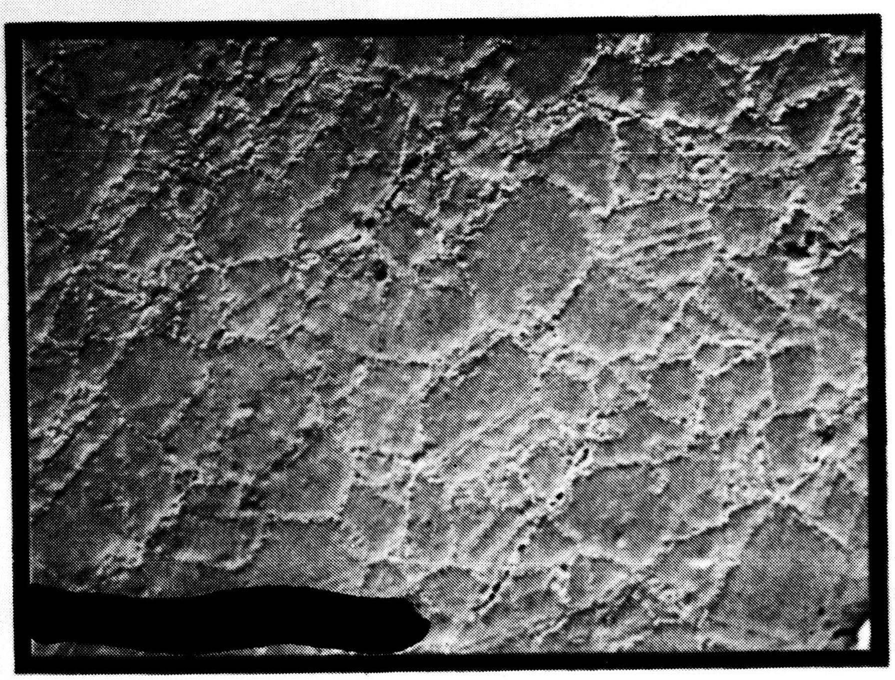

Thermal fatigue panel
(> 20,000 Thermal Cycles)

Figure 17 Microstructure of Rene' 41

1. Report No. NASA TM-87583

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Thermal Fatigue Tests of a Radiative Heat Shield Panel for a Hypersonic Transport

5. Report Date September 1985

6. Performing Organization Code 506-53-23-11

7. Author(s)
Granville L. Webb, Ronald K. Clark, and Ellsworth L. Sharpe

8. Performing Organization Report No.

9. Performing Organization Name and Address
NASA Langley Research Center
Hampton, VA 23665

10. Work Unit No.

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, DC 20546

13. Type of Report and Period Covered Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes

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17. Key Words (Suggested by Author(s))
Thermal fatigue tests
Radiative heat shield
Hypersonic transport

18. Distribution Statement
[redacted]
Until September 30, 1987
Subject Category 26

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	30	